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ABORT FROM A COPLANAR CIRCUMLUNAR ORBIT

by

N. J. Braud

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ABSTRACT

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The abort from a typical coplanar circumlunar orbit is considered, where the abort is implemented by an impulsive kick and where all abort trajectories are selected to achieve a certain reentry corridor. The investigation is conducted on the Jacobian model of the restricted three-body problem. The results provide the time to reentry, reentry velocity, and maximum distance from the earth that is reached after the abort.

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FUTURE PROJECTS BRANCH
AEROBALLISTICS DIVISION

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SUMMARY

The abort from a typical coplanar circumlunar orbit is considered, where the abort is implemented by an impulsive kick and where all abort trajectories are selected to achieve a certain reentry corridor. The investigation is conducted on the Jacobian model of the restricted three-body problem. The results provide the time to reentry, reentry velocity, and maximum distance from the earth that is reached after the abort.

SECTION I. INTRODUCTION

This report treats a problem that may arise in manned circumlunar flights, that is, the possibility of having to abort from a healthy trajectory. There are potentially many reasons for considering such a possibility. Prominent among these is the occurrence of a solar flare which results in a dangerous increase in the level of radiation within the earth-moon vicinity. Some other problems which might require such an abort are:

1. Improper separation of the injection vehicle.

2. Failure of some guidance equipment.

3. Failure of a control mechanism.

4. Power supply malfunction.

5. Human Physico - Psycho failure.

6. A material puncture of the spacecraft.

7. Failure of the life support equipment.

The objective of this report is to relate the time required to return to the earth from some point on a basic circumlunar trajectory with the amount of impulsive energy required to abort at that particular point. This analysis is conducted using the Jacobian model of the restricted three body problem in which the spacecraft of negligible mass is assumed to move in the principle plane of earth-moon motion. The distance between Earth and Moon is taken as 385.08 megameter. The results achieved from this somewhat simplified study should be useful in general and will become particularly applicable when toward the end of this decade the inclination of the lunar plane permits coplanar firings from Cape Canaveral.

SECTION II. DISCUSSIONS

A. ORBIT LAYOUT

The reference orbit which is used as a basis for the abort study lies within the principal plane of earth-moon motion. The orbit is of a purely ballistic figure-eight type that has a horizontal injection speed of about 10,893 m/s. The injection radius vector trails the earth-moon line by 126.9 degrees and corresponds to an altitude of 150 km above the surface of the earth. The reference orbit is shown in an inertial reference frame in Figure 1.

The periselenum conditions of the orbit include a close approach to the moon of 5623 km (radial distance) or 3888 km above the surface of the moon. The periselenum occurs behind the moon, 84.2 hours after injection, at which time the spacecraft is traveling 1617 m/s with respect to the moon.

The trajectory is laid out such that a single pass reentry into the earth's atmosphere would result. The reentry point is assumed to be at 120 km altitude. At that point the trajectory shows a velocity of 10918 m/s and a path angle of 96° measured from local vertical. The time of reentry is 168.6 hours after injection (7.02 days travel time).

B. IMPULSE CONSIDERATIONS

The abort from the reference trajectory is assumed to be implemented by an instantaneous impulse. In this investigation the largest amount of impulsive energy considered is that magnitude which would result in a maximum velocity increment of 2500 m/s. If the restarted S-IV stage were supplying this energy, under the assumptions of a 420 sec specific impulse, no air drag, and no gravitational acceleration during application of the impulse, then this velocity increment would correspond to a mass ratio (post-impulse to pre-impulse) of .556.

The simplifying assumption of aborting by means of an impulse, although not completely realistic, does provide a good approximation of results obtainable with high, finite thrust accelerations. For the S-IV stage mentioned above and a reasonable cutoff mass, the 2500 m/s velocity increment corresponds to a thrust period of about 20 seconds, compared to the ballistic portion of the abort trajectory in the order of 10^4 sec for most of the area of investigation.

C. ANALYSIS

1. General

The minimization of time from abort to reentry must logically be done under various constraints. The limitations considered here are that only enough propellants for a velocity correction in the order of 2500 m/s are available, and that reentry must be achieved in a positive sense with respect to earth rotation while meeting certain conditions determined previously in a separate reentry study (Reference 1).

This investigation is conducted in such a way that light is shed on the flight mechanical considerations associated with the abort problem. The approach taken is to select a reference coplanar circumlunar trajectory and then determine abort trajectories from various points on this basic orbit. Abort trajectories initiated by various incremental velocity impulses up to 2500 m/s were generated for this study, but for the sake of simplicity only three levels will be discussed. They are magnitudes of 2500, 2000 and 1500 m/s.

The time points that are considered as abort points are shown on Figure 2. Also indicated on the same figure are the directions of impulse application for each abort point. These incremental velocity directions were determined so as to still achieve reentry in the direction of the earth's rotation and with a 96 degree path angle at 120 km altitude above the earth. It was found that the incremental velocity vector orientation was relatively independent of incremental velocity magnitude. There was less than one degree difference in orientation at each abort point for the three levels considered.

The geometry of a typical family of abort trajectories from a given abort point is indicated on Figure 3, where the abort trajectories initiated at the time point of 24.9 hours on the reference orbit are shown. The geometry displayed by the abort trajectories in Figure 3 is generally typical of that for any other abort trajectory included in this report.

In the following paragraphs there will be discussions of the relationships between the incremental abort velocities and the time required from abort to reentry, the velocity at reentry and the maximum distance from the earth achieved by the vehicle after abort.

2. Time From Abort to Reentry

Assuming that for any reason a manned circumlunar flight should require aborting, it has been stated that the minimization of time from abort to reentry would probably be desirable. To assist in an analysis of this problem, a display of the time from abort to reentry is shown on Figure 4 as a function of the distance from the earth at the time of abort. The time from abort to reentry is displayed for the three incremental-velocity levels of 1500, 2000 and 2500 m/s.

Time from abort to reentry becomes more meaningful when compared with corresponding values on the curve representing the time remaining to reentry on the uninterrupted reference path, also shown on Figure 4. Attention is brought to the fact that the reference trajectory history is divided into an outbound and an inbound leg of the flight. This division is made at the periselenum which is approximately 391,000 km from the earth. The behavior of the quantities shown very near to periselenum would require a denser survey than was made, and so is not shown here.

From this figure it can be seen that substantial savings in time to reentry can be realized by aborts on the outbound leg of the reference orbit. The advantage to be gained on the inbound leg is not as great in comparison, and for reasons which are indicated in a later paragraph, an abort on the inbound leg may not be advisable.

Referring again to Figure 3, it may be seen that the return legs of the abort trajectories studied form a relatively small volume in inertial space. The earth-referenced position at which the desired space referenced reentry is achievable then is determined mainly by the time spent in flight while the earth rotates. This time is seen to vary considerably with the magnitude of the incremental velocity (Figure 4). This parameter could therefore be chosen at a value that produces the desired earth related position at reentry, and would depend on the distance from the earth at the time of abort. There may be a number of such solutions which differ by multiples of 24 hours.

Choosing the best of these solutions that are also less than the 2500 m/s limit on velocity increment produces the step-like time-savings function shown in Figure 5. The flat segments result from hitting the same reentry time point (same rotational position of earth to match same space fixed reentry position) and therefore, the same time-saving with respect to the constant reference reentry time point. Comparing this curve with the 2500 m/s incremental velocity curve shows the penalty paid in time-savings for meeting the constraint of an earth fixed reentry position.

3. Reentry Velocity

Thus far consideration has only been given to the minimization of the time from abort to reentry. It might be noted that certain tradeoffs should be kept in mind when considering the minimization of this time. One of the additional conditions which are affected by aborting is the reentry velocity.

The behavior of the reentry velocity for the various abort trajectories as a function of the distance from the earth at the time of abort is shown in Figure 6. Attention is directed to the standard or reference reentry velocity and the escape velocity magnitude for the reentry altitude that are indicated on the figure. The reentry velocity which results from aborts on the outbound leg of the basic orbit shows some interesting behavior. For aborts early in the flight, there is an actual reduction in reentry velocity from that of the reference reentry. As the point of abort nears the moon there is an increase in the resultant reentry velocity above the reference value, but in no case does it exceed escape velocity.

The situation on the inbound or return leg is quite different. There not only is the reference reentry velocity exceeded, but almost all aborts result in velocity magnitudes greater than the local escape velocity at the reentry altitude. The more severe heating encountered with these higher reentry velocities may impose restrictions on the impulse application on the return leg.

4. Maximum Distance from the Earth Achieved by Abort Trajectories

Another feature of the abort trajectory which may be considered is the apogee distance or the maximum distance from the earth after abort. The aborts near the earth on the outbound leg result in apogee distances of different magnitudes depending upon the abort impulses. After having gone a certain distance on the reference orbit, all abort trajectories return directly to the earth with no further increase in the distance from the earth. The information on maximum distances from the earth after abort is contained on Figure 7.

The distances for three levels of incremental velocities are shown as well as the line for which the abort points themselves are the maximum.

SECTION III. CONCLUSIONS

The flight mechanical features of in-plane aborting from a typical circumlunar orbit have been presented. From these it is concluded that abort propellants in the magnitude of a 2500 m/s incremental velocity are sufficient to effect reasonable aborts on the reference trajectory.

The abort on the inbound leg of the reference orbit does not seem to be too advantageous because large flight time savings are not realized and in addition, the abort kick causes an increase in the reentry velocity above that of the reference orbit.

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1. "Flight Mechanics of Reentry after Circumlunar Flight by Means of Various Lifting Techniques," by E. R. Teague, MNN-M-AERO-4-60, dated September 15, 1960.

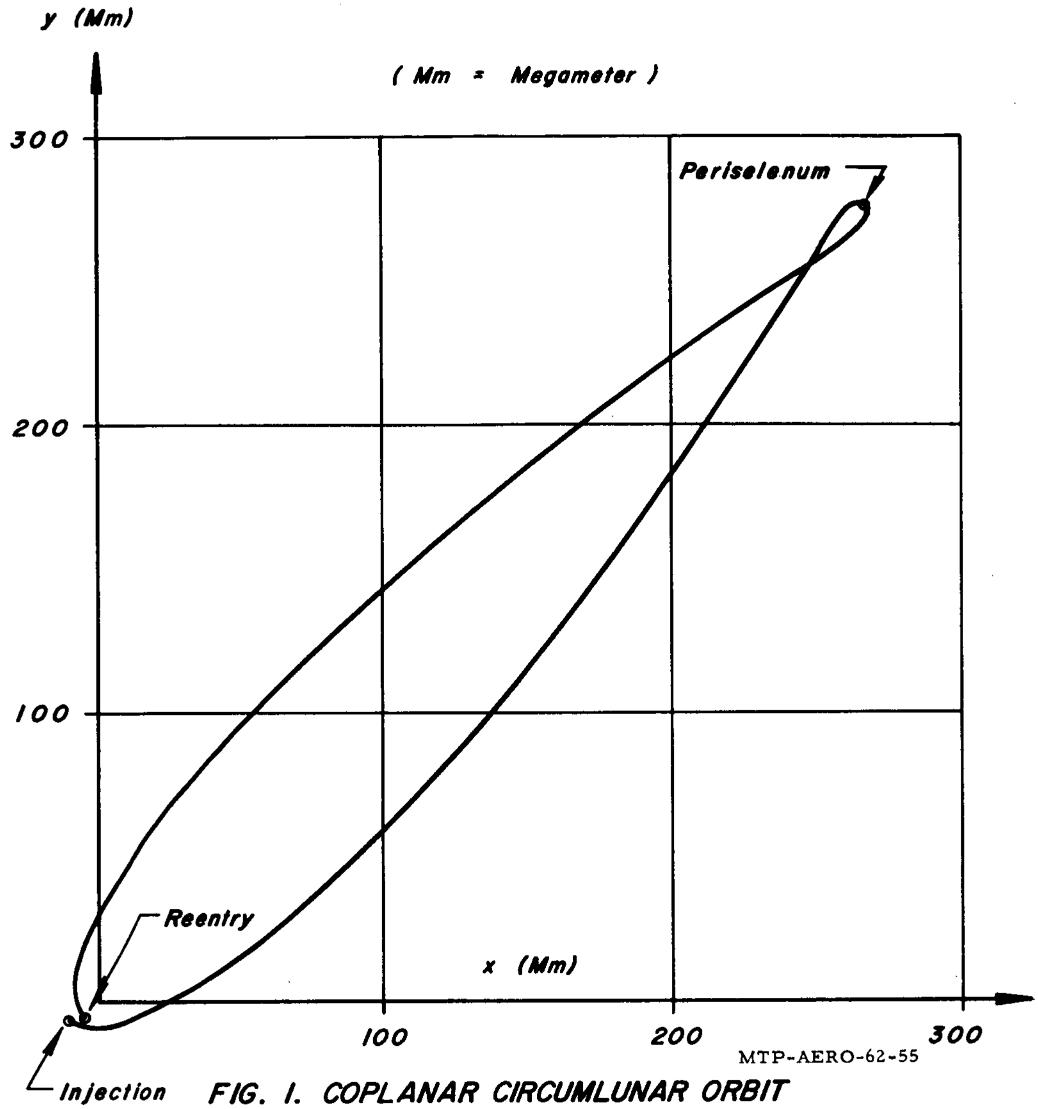

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FIG. 1. COPLANAR CIRCUMLUNAR ORBIT
Space - Fixed Coordinates

INJECTION
Path Angle = 90 deg, Lunar Lead Angle = 126.9 deg, Altitude = 150 km, Velocity = 10,893 m/s

PERISELENUM
Time = 84.23 hr, Altitude = 3,888 km, Velocity = 1,617 m/s

REENTRY
Path Angle = 96 deg, Time = 168.6 hr, Altitude = 120 km, Velocity = 10,918 m/s

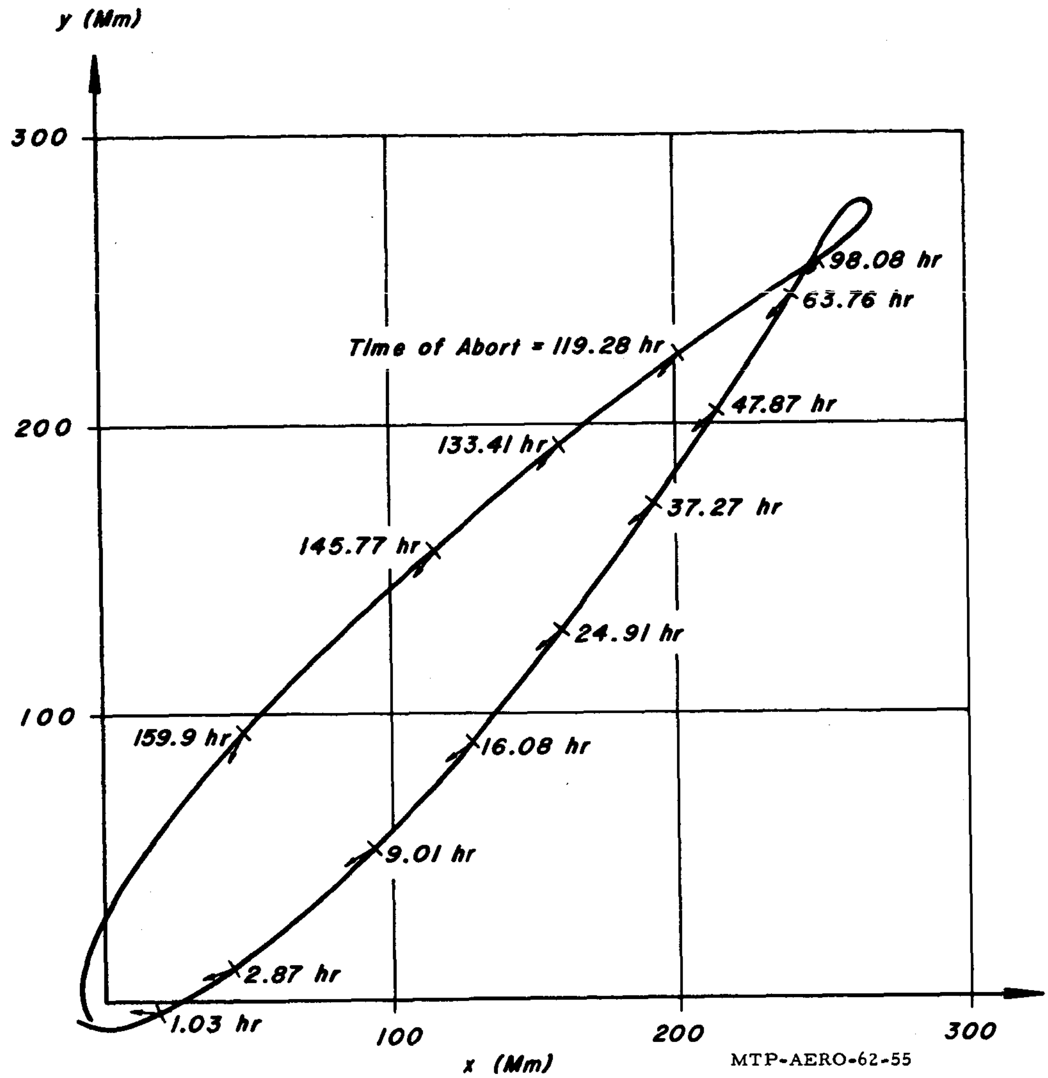

FIG. 2. GEOMETRY OF ABORT IMPULSES
AT VARIOUS TIMES OF ABORT
FOR A VELOCITY INCREMENT OF 2,000 m/s

Space-Fixed Coordinates

ABORT CONDITIONS

Time = 24.91 hr | *Distance = 208.438 Mm*

Incremental Abort Velocity (m/s)	2,500	2,000	1,500
Abort to Reentry Time (hr)	27.39	34.48	45.18
Reentry Velocity (m/s)	10,889.5	10,848.1	10,831.4

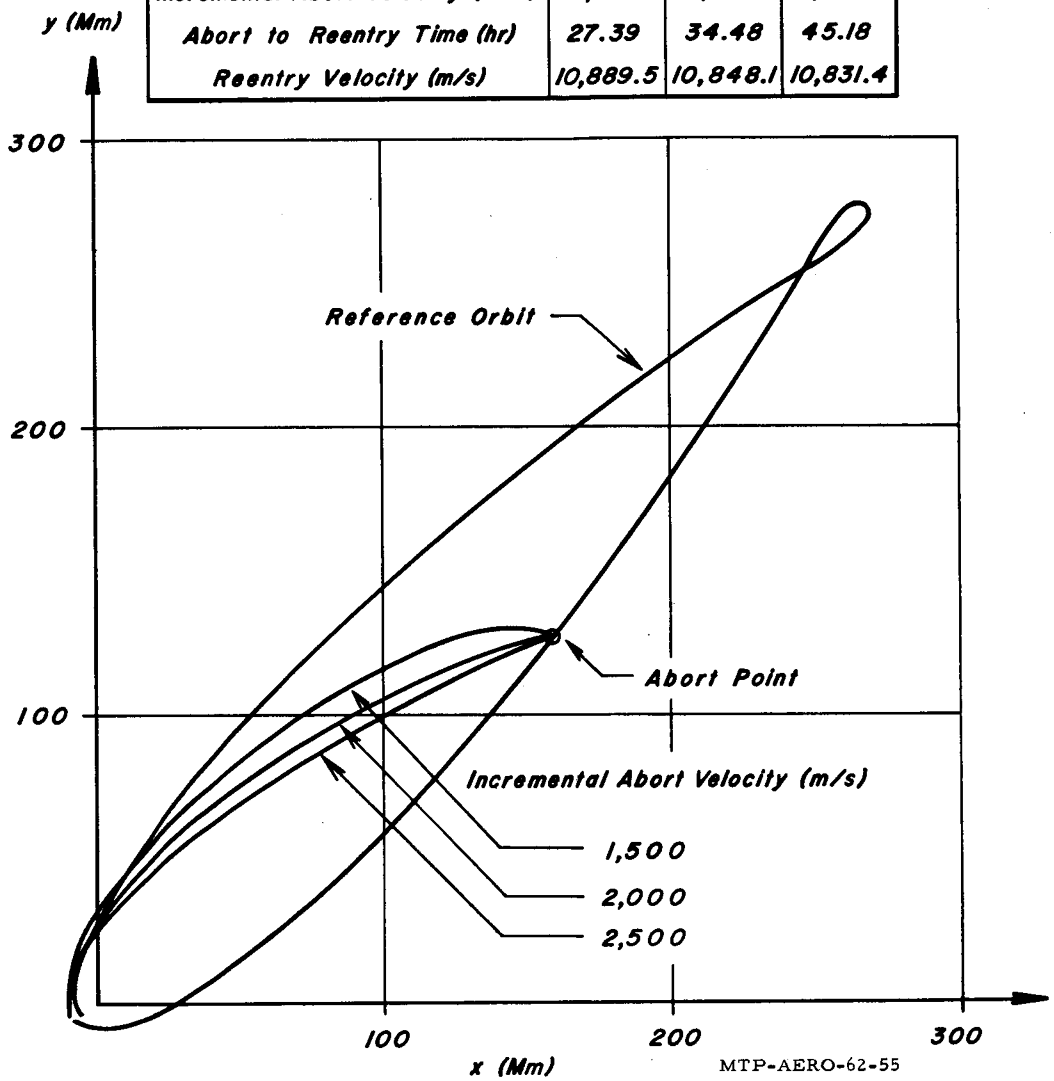

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FIG. 3. ABORT TRAJECTORY GEOMETRY
FOR 3 INCREMENTAL VELOCITIES
FROM THE 24.91 hr TIME POINT ON THE REFERENCE ORBIT
Space-Fixed Coordinates

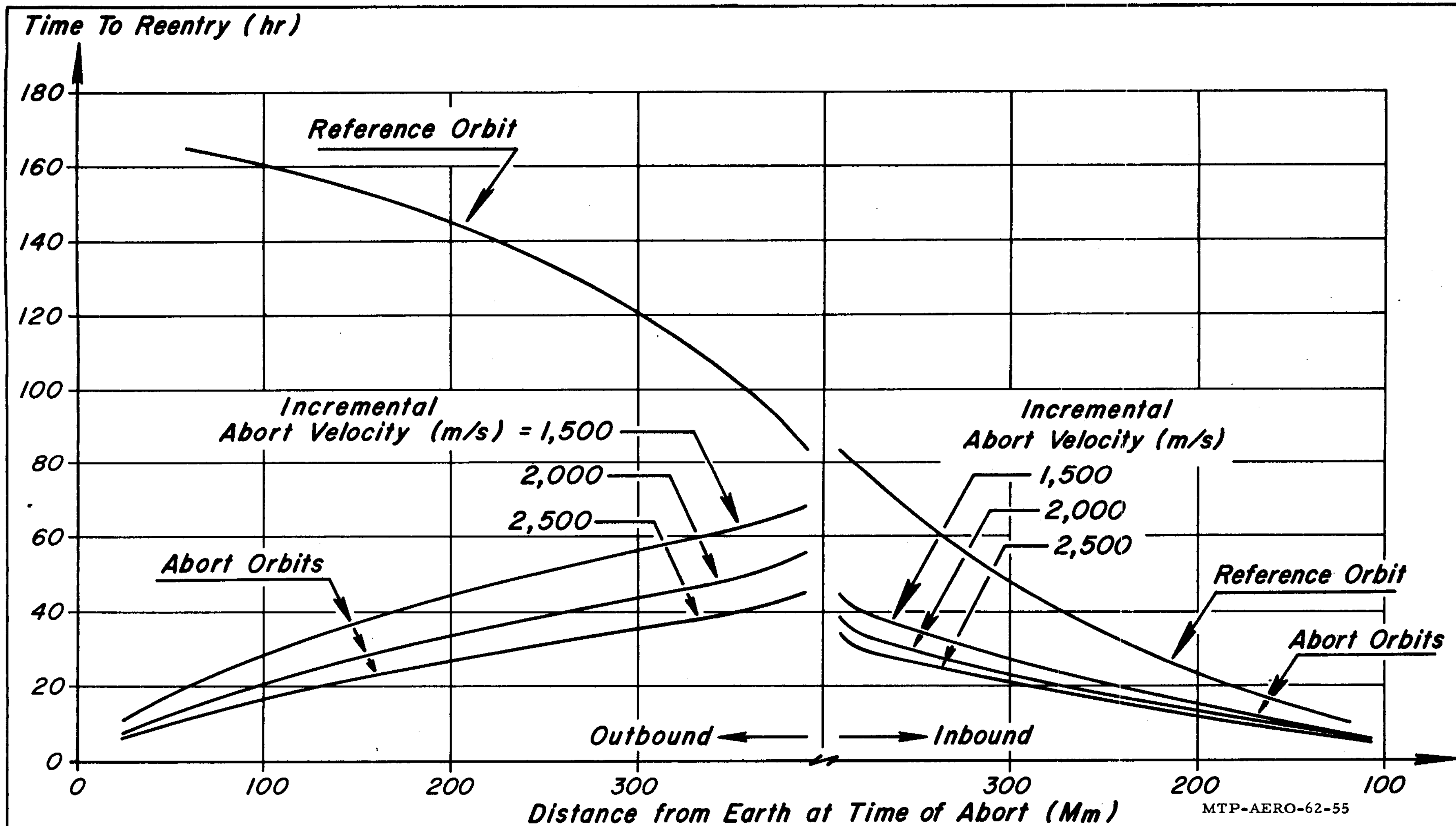

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FIG. 4. COMPARISON OF THE TIME FROM ABORT TO REENTRY ON VARIOUS ABORT TRAJECTORIES WITH THE TIME TO REENTRY ON THE REFERENCE ORBIT

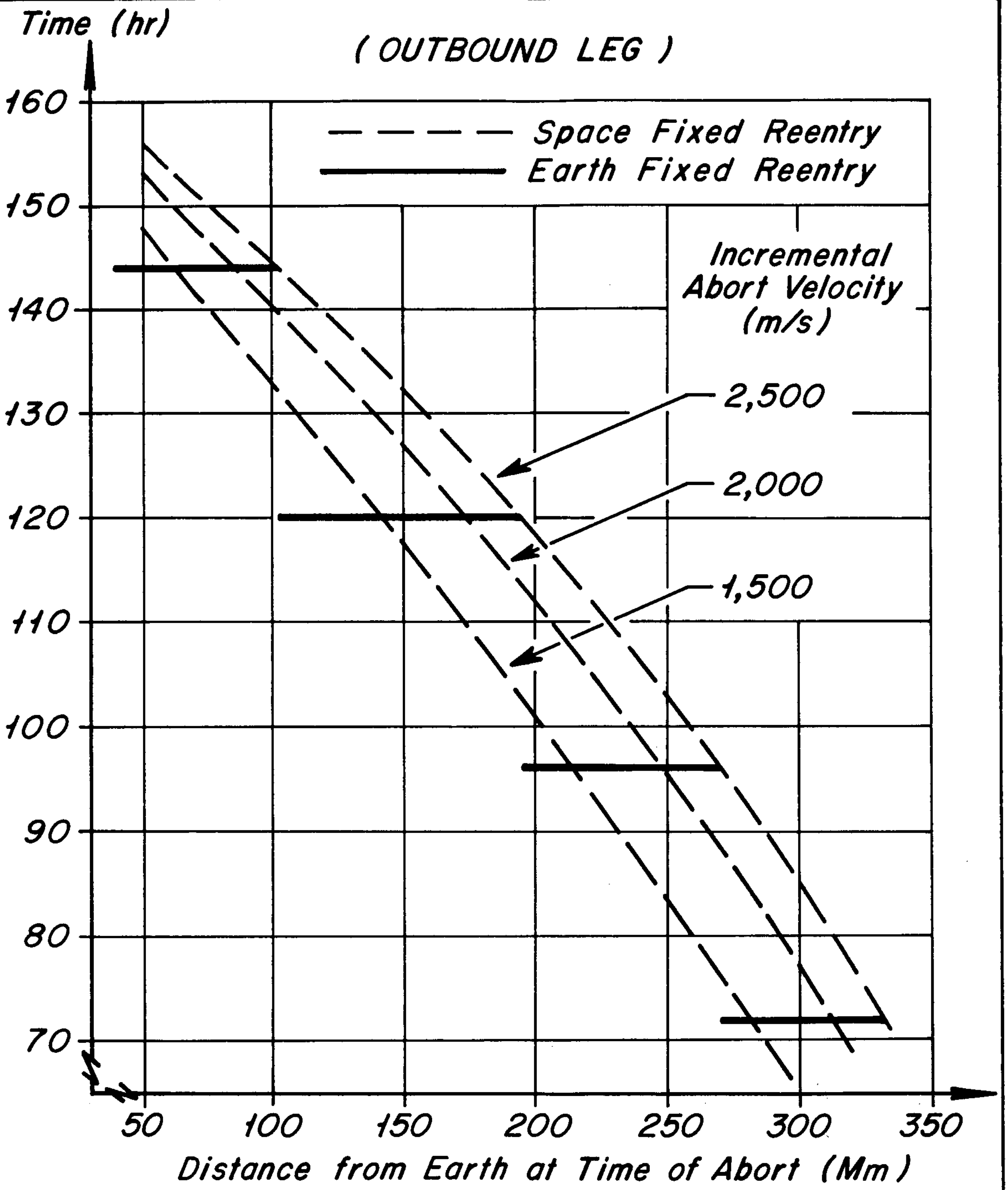

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FIG. 5. FLIGHT TIME SAVED
BY ABORT RETURN OVER REFERENCE RETURN

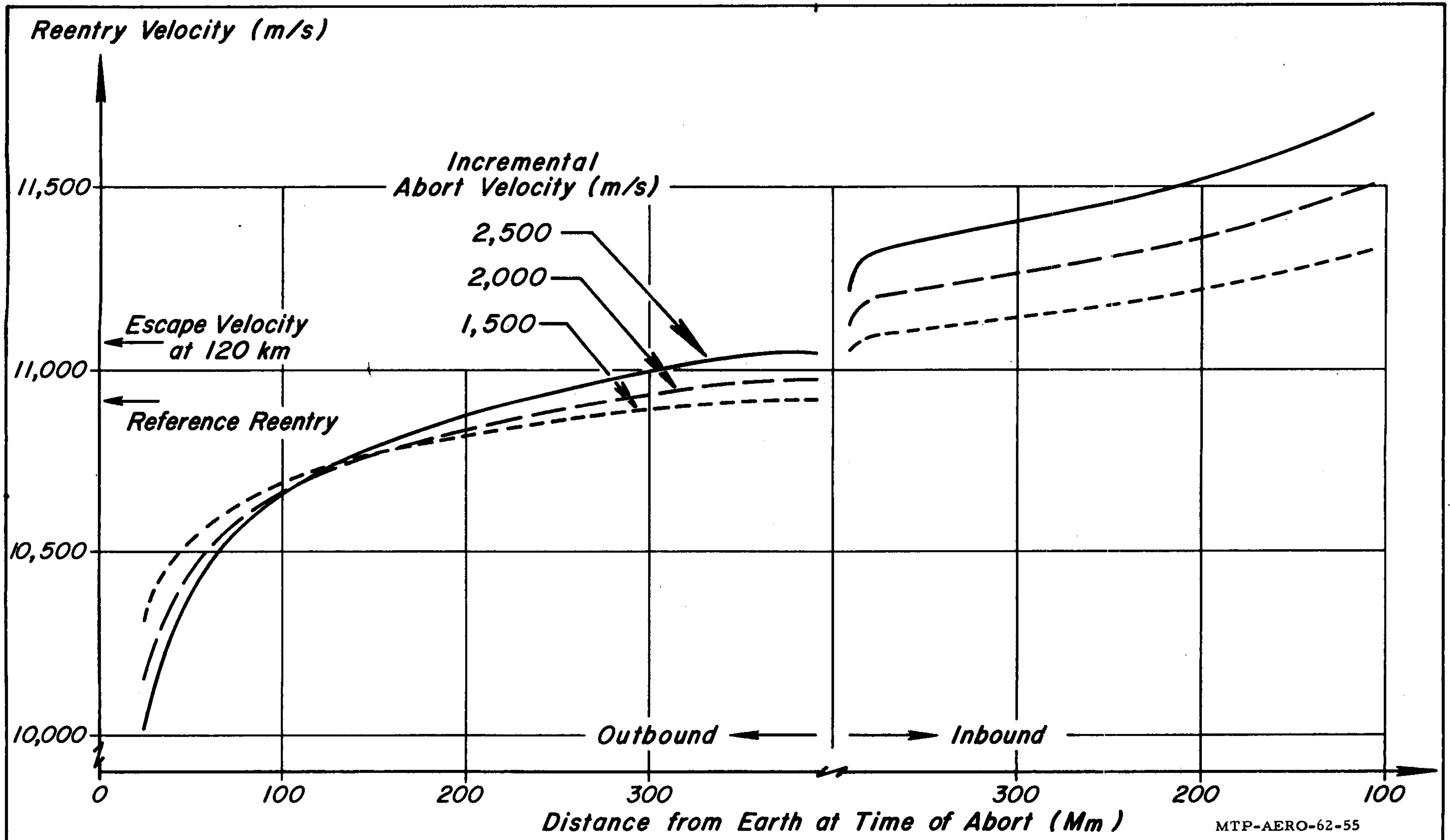

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FIG. 6. REENTRY VELOCITY RESULTING FROM VARIOUS ABORT TRAJECTORIES

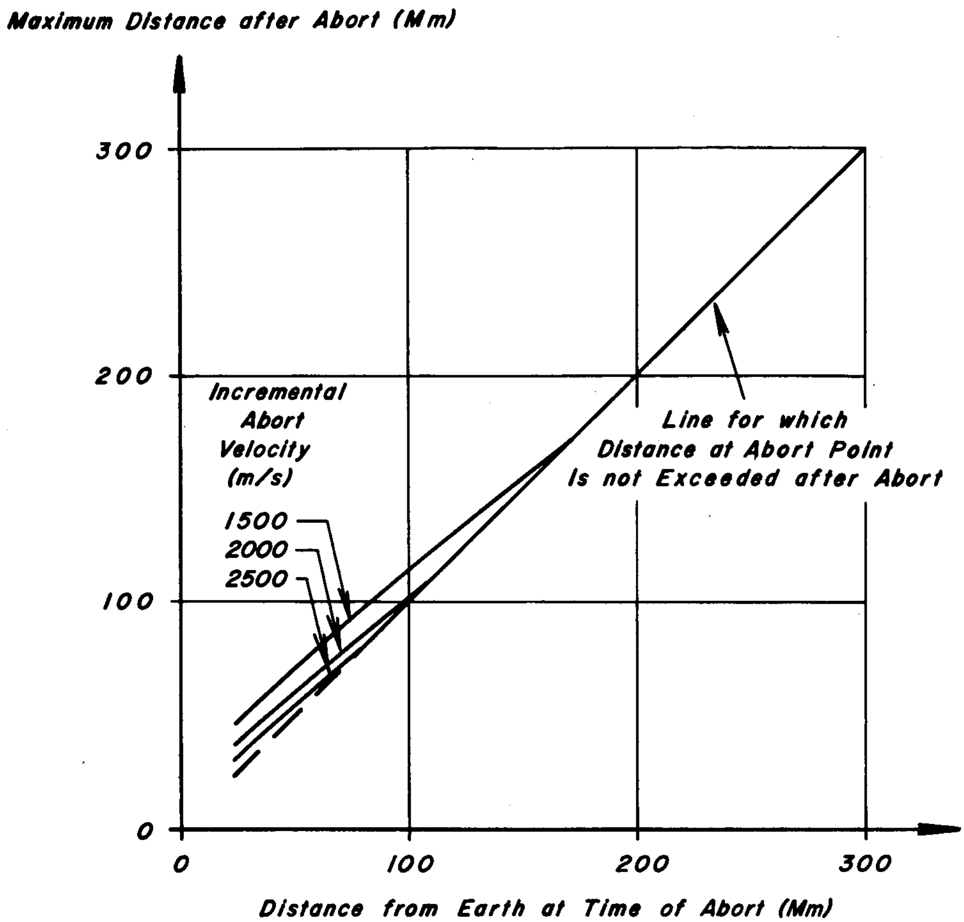

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FIG. 7. MAXIMUM DISTANCE FROM EARTH ACHIEVED AFTER ABORT

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